



MICHIGAN STATE
UNIVERSITY UNIVERSITY

Alternative Superconducting Drift Tube Linac R&D

(R&D Categories: Driver & Post-Accelerator Linacs)

Terry L. Grimm

August 2003

Outline

- Objective of R&D
- Superconducting drift tube linac (SC-DTL) cavities for RIA
 - 80.5 MHz $\beta = 0.041$ quarter-wave resonator (Legnaro)
 - 80.5 MHz $\beta = 0.085$ quarter-wave resonator (RIA)
 - 322 MHz $\beta = 0.285$ half-wave resonator (RIA)
- Why 80.5 MHz?
- SC-DTL R&D program
 - Cavities
 - Cryomodule -- realistic operating conditions

Objective

- **Carry out R&D on critical long-lead items whose demonstration is required to confidently cost and build RIA**
 - Limited R&D funds
 - Limited manpower
 - Limited time
- **Demonstrate all cavities and cryomodules**
 - Near term within budget constraints
 - Realistic operating conditions
 - Horizontal cryomodule, tuner, couplers, microphonics control, magnets,



Alternative SC Drift Tube Linac [1]

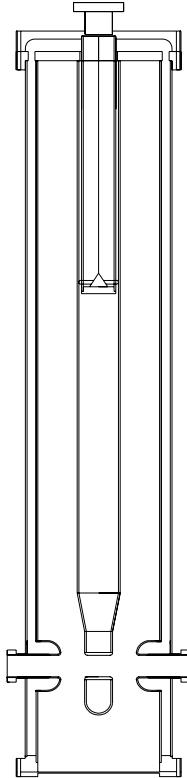
MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

- **Collaboration with INFN Legnaro**
- **Accelerate beam from 0.3-85 MeV/u ($\beta \sim 0.025-0.40$)**
 - ~25% of the driver linac voltage
 - ~400 MV of accelerating gradient
- **Two-gap cavities have broad velocity acceptance**
 - 3 cavity types can cover this range
- **Frequency jumps at strippers only**
 - Take advantage of stripping chicane to improve longitudinal matching
- **Passive microphonics control**
- **Post-accelerator will use same cavities**

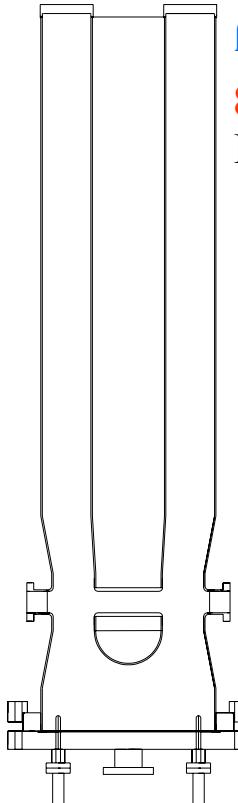


MSU RIA Driver Linac Cavities - [1]

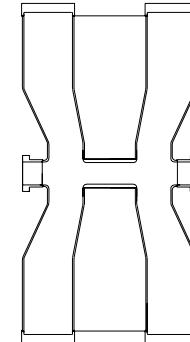
MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY



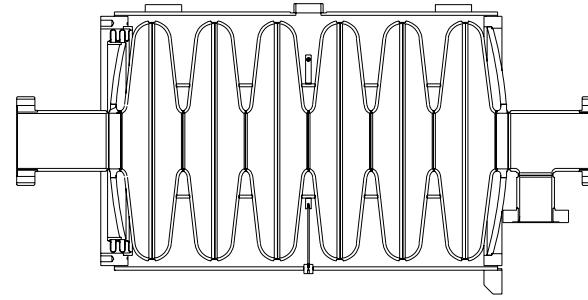
$\beta_{\text{opt}}=0.041$
80.5MHz
Legnaro



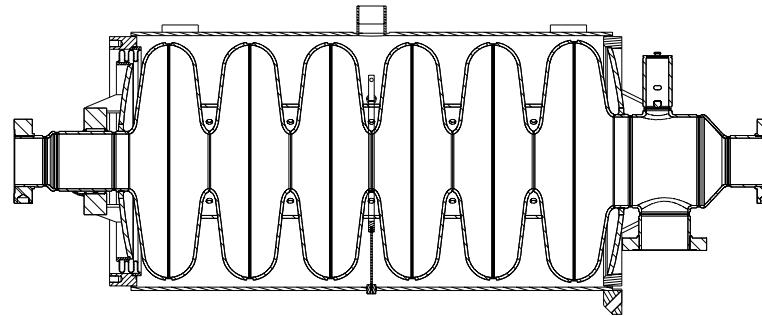
$\beta_{\text{opt}}=0.085$
80.5MHz
MSU



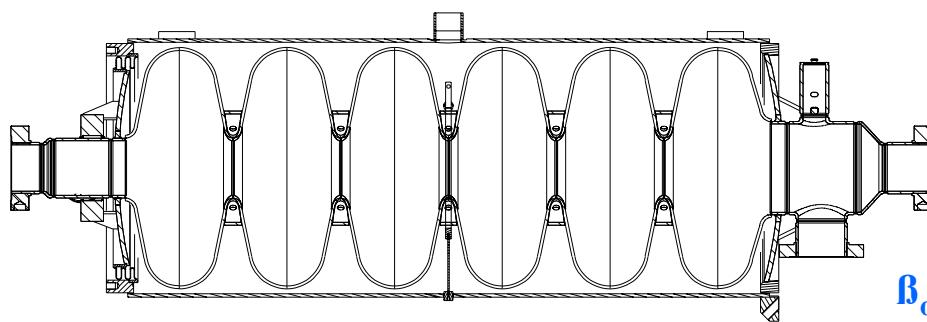
$\beta_{\text{opt}}=0.285$
322MHz
MSU



$\beta_{\text{opt}}=0.49$
805MHz
MSU/JLAB



$\beta_{\text{opt}}=0.63$
805MHz
SNS



$\beta_{\text{opt}}=0.83$
805MHz
SNS



MSU RIA Driver Linac Cavities - [2]

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

MSU 10 th (80.5 MHz) Sub-harmonic RIA Driver						
Type	$\lambda/4$	$\lambda/4$	$\lambda/2$	6-cell	6-cell	6-cell
β_{opt}	0.041	0.085	0.285	0.49	0.63	0.83
f (MHz)	80.5	80.5	322	805	805	805
V _{acc} (MV)	0.54	0.97	1.04	4.3	6.89	11.14
T(K)	4.2	4.2	4.2	2	2	2
Q _o	2.5×10^8	2.5×10^8	2.5×10^8	5×10^9	5×10^9	5×10^9
P _o (W)	2.74	9.1	21.8	21.4	34	51.4
U(J)	1.36	4.52	2.68	21.1	33.6	50.8
R/Q(Ω)	424	416	199	173	279	483
R _s (n Ω)	73	76	244	31	36	52
E _{peak} (MV/m)	16.2	16.5	16.5	27.3	27.4	26.9
B _{peak} (mT)	36	38.4	45.3	53.9	57.8	58.1

$$P_o = \frac{V_{acc}^2}{R}$$

$$Q = \frac{\omega U}{P_o}$$

$$\frac{R}{Q} = \frac{V_{acc}^2}{\omega U}$$

$$V_{acc} = \frac{1}{q} |Maximum\ energy\ gain\ of\ optimum\ particle|$$



Why 80.5 MHz?

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

- Higher frequency/shorter QWR
 - Decreased microphonics
- Operating experience
 - ANL 48 MHz Fork VCX 200 Hz bandwidth
 - Legnaro 80 MHz QWR Passive 7 Hz bandwidth
- RIA 10th harmonic design (80.5 MHz)
 - Passive mechanical damper without VCX or piezo
 - Use existing Legnaro 80 MHz design
 - Modifications: β = 0.047 to 0.041
2 cm to 3 cm aperture
 - EM simulations and design complete
- Next two cavities have less microphonics problems
 - Larger inner and outer coaxial diameters (10.4 & 24 cm)
- Adequate longitudinal and transverse acceptance



Concern with VCX

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

- Components inside cryomodule
 - Difficult to access for repair
- ATLAS (VCX experience <100 MHz, operation 1984-99)
 - 17 cryostat openings due to VCX (out of 9)
- VCX operation at 350 MHz for double-spoke
 - No experience or reliability
 - Major development program
- Inherent phase and amplitude error
- Thermal load to liquid helium and nitrogen
- Liquid nitrogen system and safety issues (ODH)



Alternative SC-DTL R&D

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

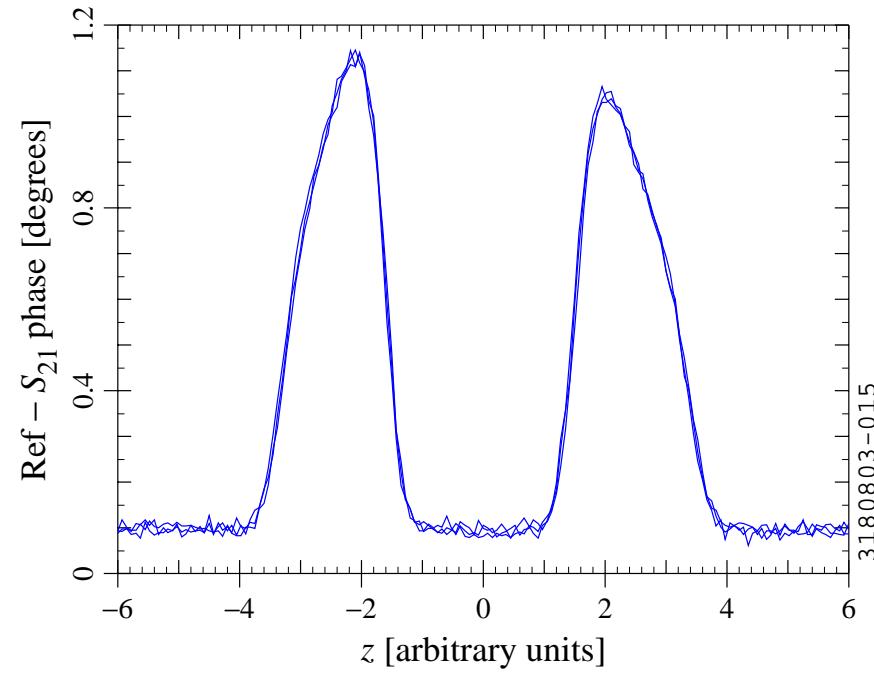
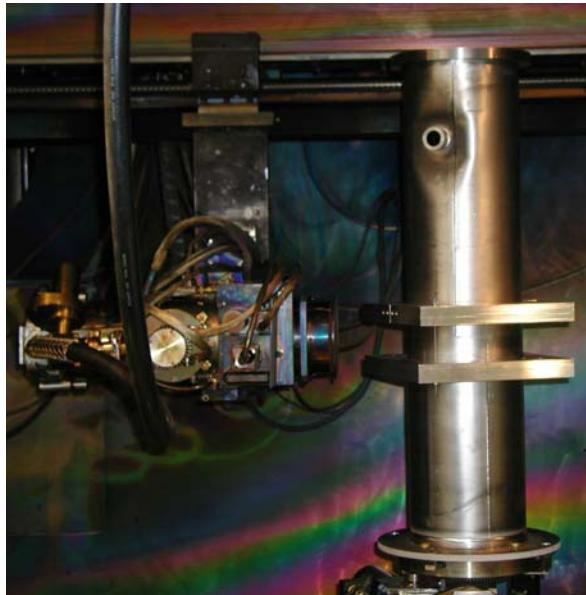
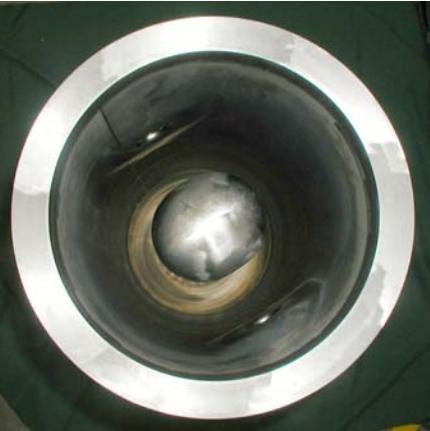
• Cavity R&D

- 80.5 MHz $\beta=0.041$ QWR
 - Demonstrated at INFN Legnaro
- 80.5 MHz $\beta=0.085$ QWR
 - Test in Fall 2003
- 322 MHz $\beta=0.285$ HWR
 - Successfully tested in 2002 at MSU

• Cryomodule R&D

- Same rectangular cryomodule as elliptical $\beta=0.47$
- Cavities and 9 T solenoid
- Test under realistic operating conditions
 - Horizontal cryomodule, tuner, couplers, microphonics control, magnets,

80.5 MHz QWR $\beta=0.085$ R&D Program



Bead-pull of QWR 80.5MHz,
 $\beta=0.085$ (2003)

$\Delta E/E \approx 4\%$

322 MHz HWR $\beta=0.285$ R&D Program [1]

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

BCP ETCH
 $\sim 120\mu\text{m}$

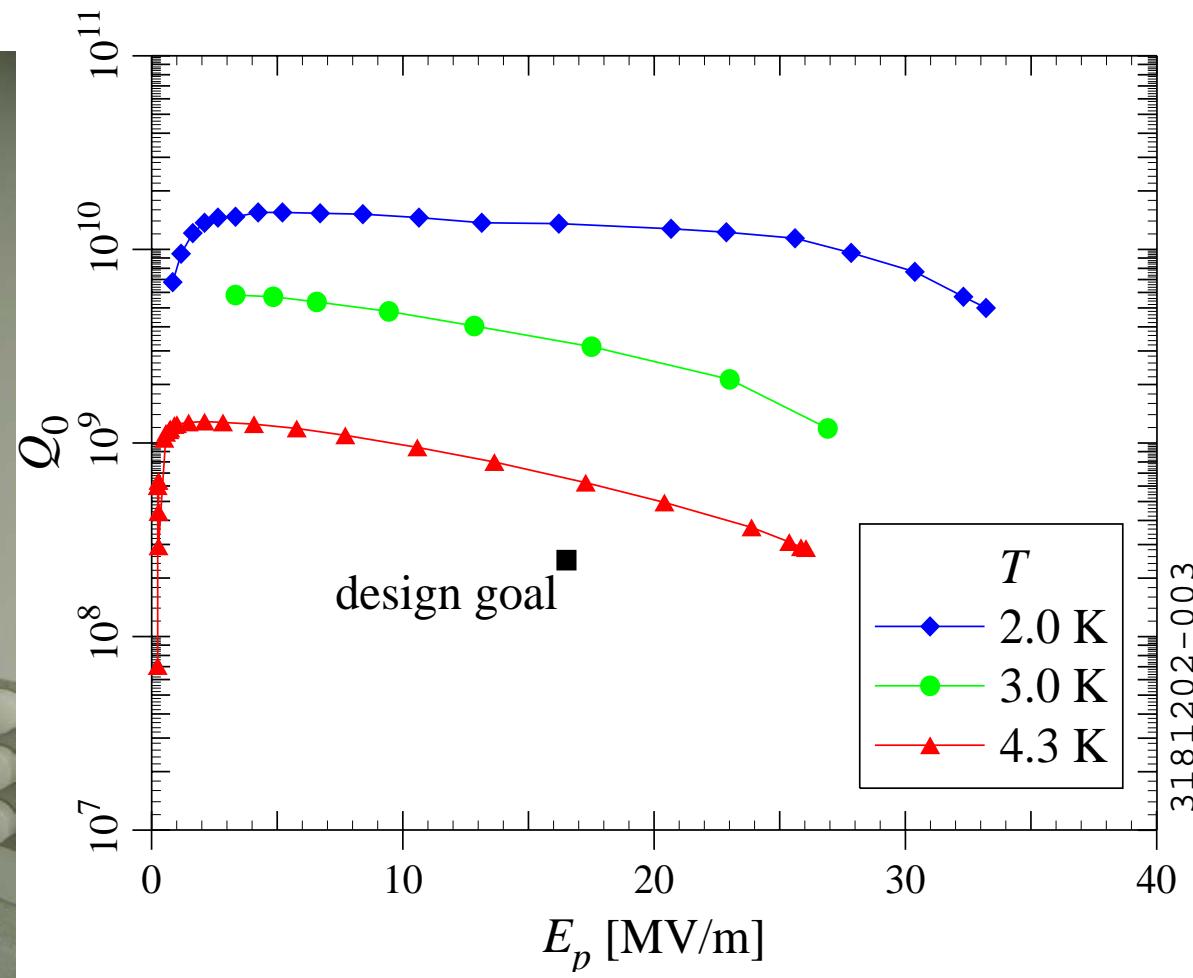
- 322 MHz, $\beta=0.285$, $\lambda/2$
- Design, fabrication at MSU
- Commercial e-beam welding



HPR
 $\sim 60\text{min}$

322 MHz HWR $\beta=0.285$ R&D Program [2]

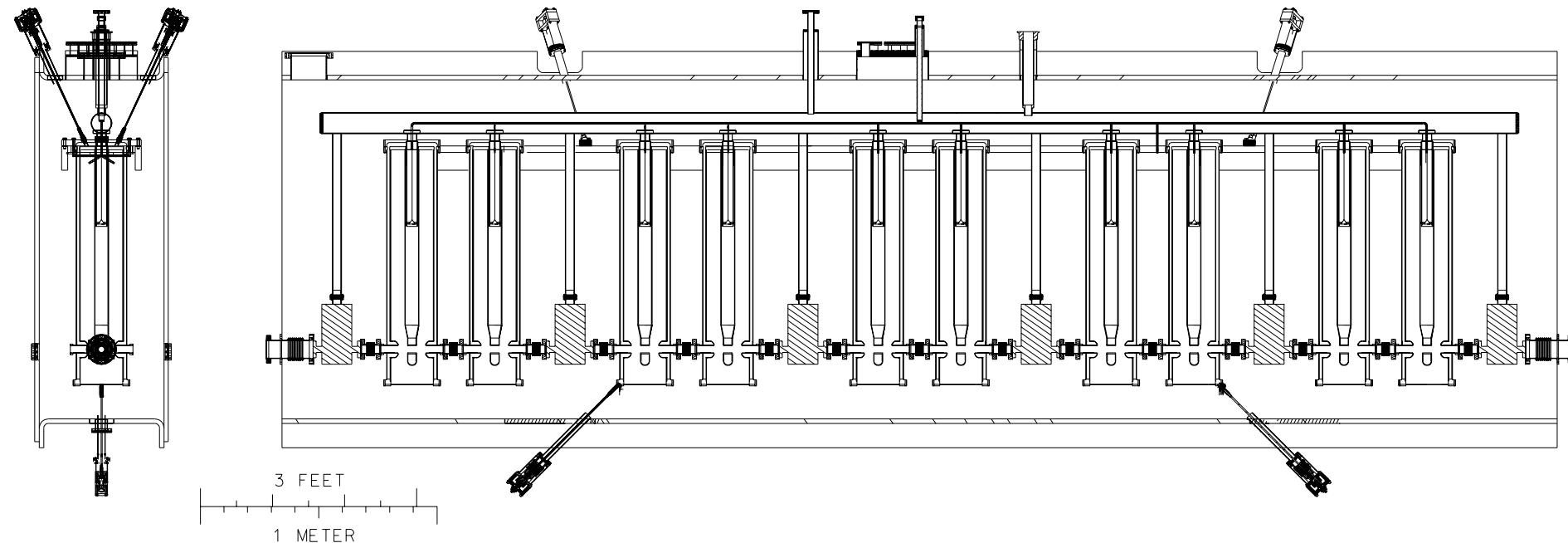
MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY





80.5MHz QWR $\beta=0.041$ Cryomodule

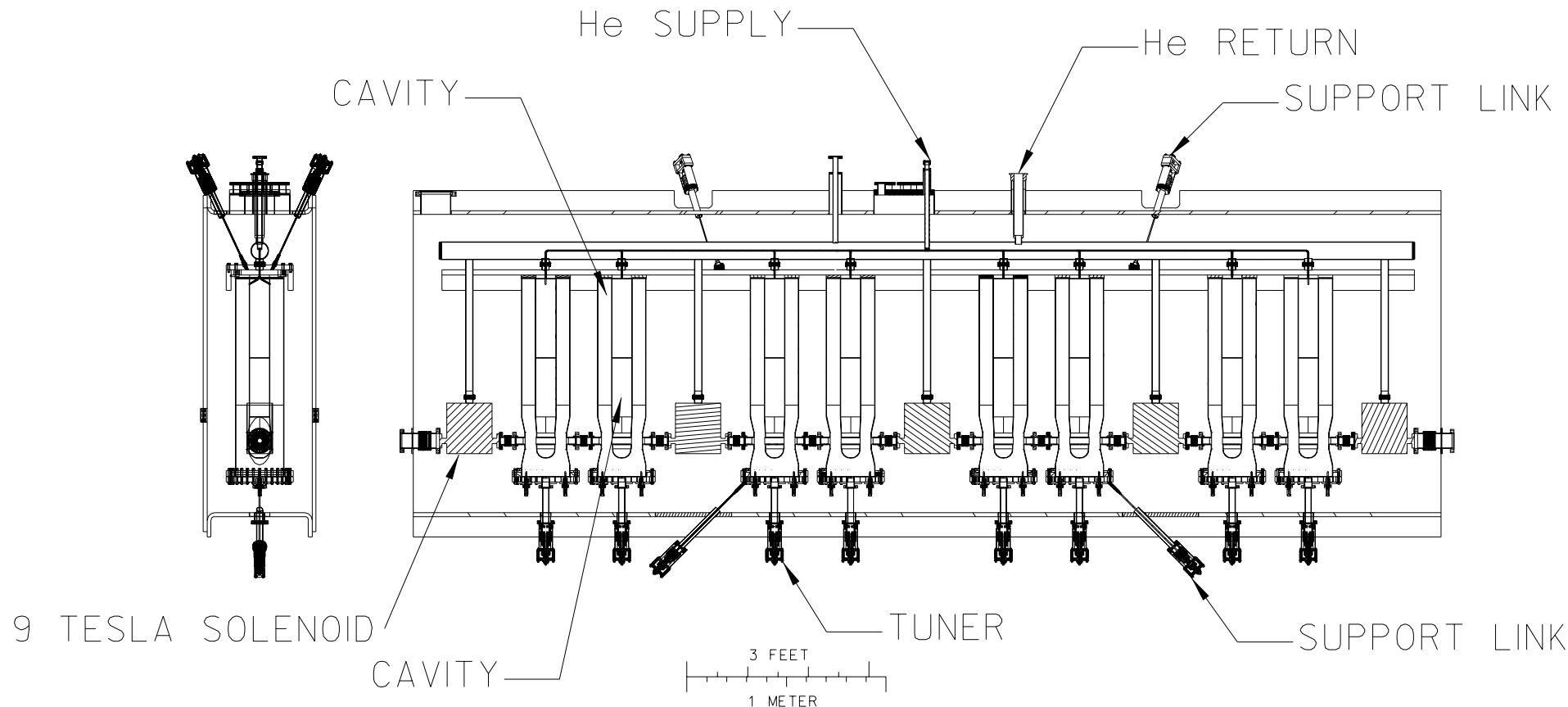
MICHIGAN STATE
UNIVERSITY UNIVERSITY





80.5MHz QWR $\beta=0.085$ Cryomodule

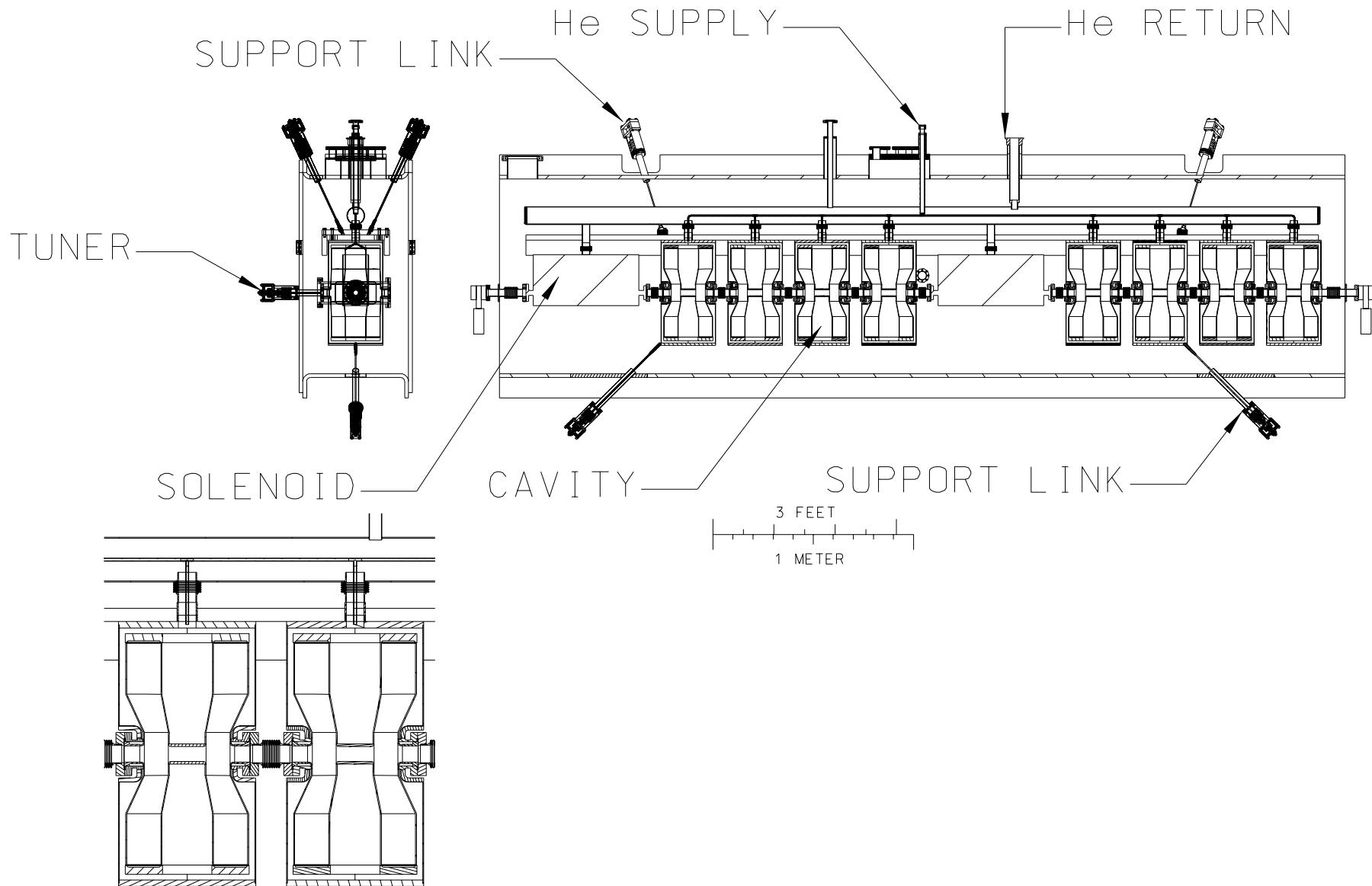
MICHIGAN STATE
UNIVERSITY UNIVERSITY





322MHz HWR $\beta=0.285$ Cryomodule

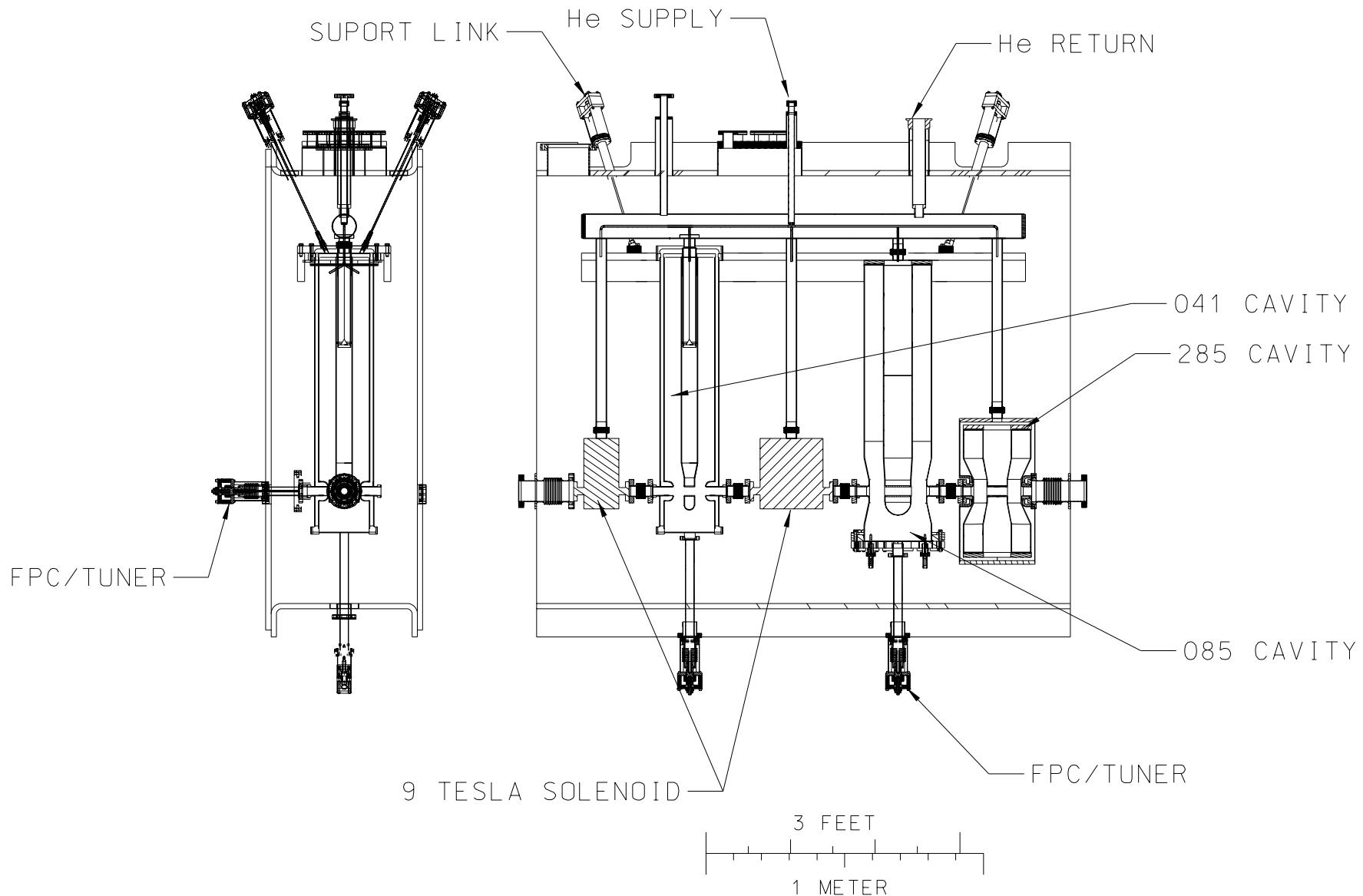
MICHIGAN STATE
UNIVERSITY UNIVERSITY





Prototype Cryomodule (SC-DTL & Solenoids)

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY





International Collaborations

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

- **INFN Legnaro (A. Facco)**
 - Drift-tube cavities for RIA
 - Industrial quarter-wave resonator at Zanon
- **JLab (P. Kneisel) & INFN Milan (C. Pagani)**
 - $\beta=0.49$ elliptical cavity and cryomodule
- **DESY (S. Simrock)**
 - Low-level rf & microphonics control
- **TRIUMF (R. Laxdal)**
 - $\lambda/4$ resonator processing & cryomodule designs
- **ACCEL of Germany**
 - Low beta cavities



Alternative SC-DTL Funding

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

- Work started in 2002
- Funding from DOE

FY2003	\$70k
FY2004	\$875k**

**Requested funding to complete
Alternative SC-DTL R&D



Alternative SC-DTL Summary

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

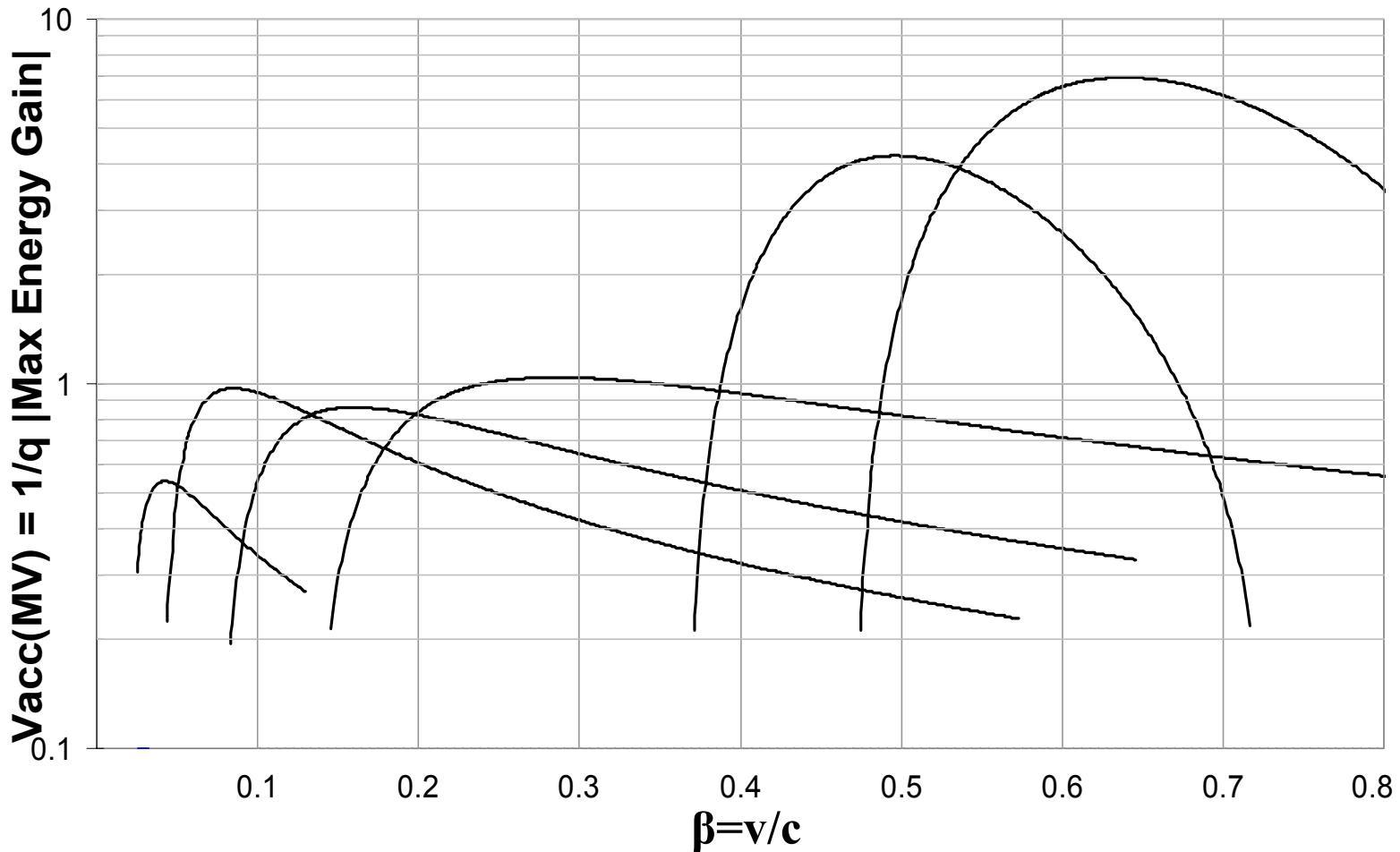
- Three cavity types required for 0.3-85 MeV/u
 - Two demonstrated ($\beta=0.041$ & 0.285)
 - $\beta=0.085$ will be tested in the Fall 2003
- SC-DTL Cryomodule
 - Cryomodule assembly complete in Summer 2004
 - Test under realistic operating conditions in 2004
- By end of 2004 SC-DTL R&D will be complete
- RIA linac design and production plans can be finalized
- Post accelerator will use both 80.5 MHz QWRs



BACKUPS

TTs of RIA Driver Linac Cavities

MICHIGAN STATE
UNIVERSITY UNIVERSITY





10th Sub-Harmonic Ria Driver Linac

MICHIGAN STATE
UNIVERSITY UNIVERSITY

MSU 10 th (80.5 MHz) Sub-harmonic RIA Driver								
Type	RFQ	$\lambda/4$	$\lambda/4$	$\lambda/4^*$	$\lambda/2$	6-cell	6-cell	6-cell
β_{opt}		0.041	0.07	0.16	0.285	0.49	0.63	0.83
f (MHz)	80.5	80.5	80.5	161	322	805	805	805
V _{acc} (MV)		0.54	0.86	0.86	1.04	4.2	6.89	11.1
T(K)		4.2	4.2	4.2	4.2	2	2	2
Q _o		2.5x10 ⁸	2.5x10 ⁸	2.5x10 ⁸	2.5x10 ⁸	5x10 ⁹	5x10 ⁹	5x10 ⁹
P _o (W)		2.74	5.17	7.8	21.8	22.1	34	51.4
U(J)		1.36	2.56	1.91	2.68	21.8	33.6	50.8
R/Q(Ω)		424	571	381	199	160	279	483
R _s (n Ω)		73	104	140	244	27	36	52
E _{peak} (MV/m)		16.2	16.3	16.5	16.5	27.3	27.4	26.9
B _{peak} (mT)		36	38.4	37.8	45.3	55.2	57.8	58.1

*tapered drift tube to cancel vertical steering

$$V_{acc} = \frac{1}{q} |Maximum\ energy\ gain\ of\ optimum\ particle|$$

$$P_o = \frac{V_{acc}^2}{R}$$

$$Q = \frac{\omega U}{P_o}$$

$$\frac{R}{Q} = \frac{V_{acc}^2}{\omega U}$$

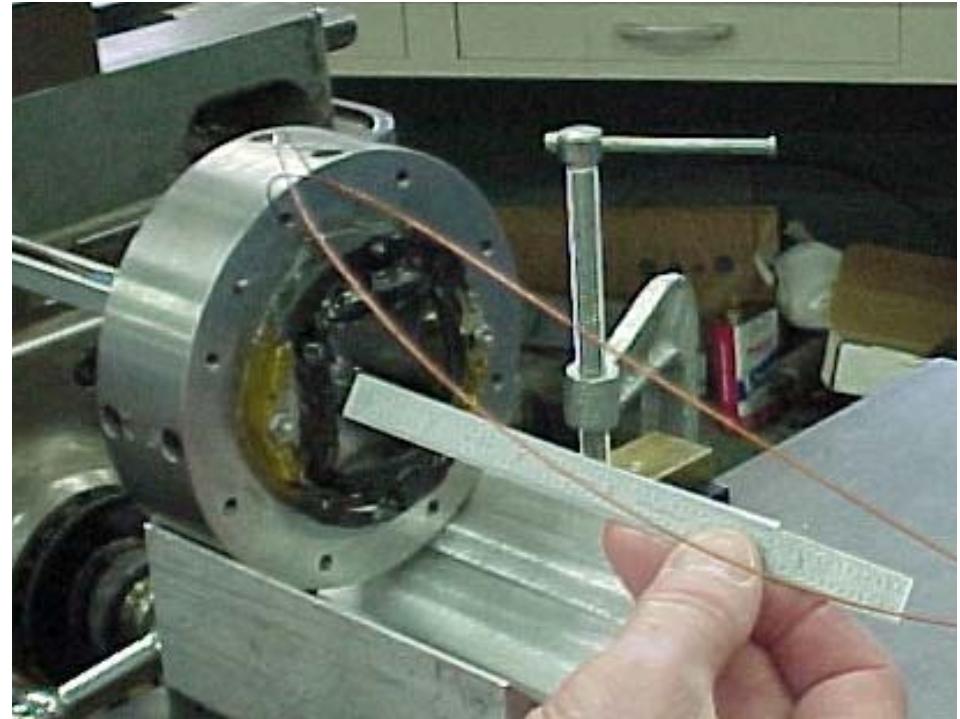
Superferric SC Quadrupoles

MICHIGAN STATE
UNIVERSITY UNIVERSITY

- Appropriate for SRF Linac applications
- Provides focusing element within cryostat environment

Specifications

<10mG stray field at 10cm
50mm length
40mm bore
31 T/m





References

MICHIGAN STATE UNIVERSITY MICHIGAN STATE UNIVERSITY

2001 Particle Accelerator Conference, Chicago IL (2001)

Niobium Cavity Development for the High-Energy Linac of the Rare Isotope Accelerator, C.C. Compton et al.

10th Workshop on RF Superconductivity, Tsukuba, Japan (2001)

Superconducting RF Activities at NSCL, T.L. Grimm et al.

Studies of Multipacting in Axisymmetric Cavities for Medium-velocity Beams, W. Hartung.

2002 European Particle Accelerator Conference, Paris, France (2002)

Input Coupling and Higher-order Mode Analysis of Superconducting Axisymmetric Cavities for the Rare Isotope Accelerator, T.L. Grimm, et al.

21st International Linac Conference, Gyeongju, Korea (2002)

The Misalignment and RF Jitter Analysis for the RIA Driver Linac at the NSCL, X. Wu, et al.

2003 Particle Accelerator Conference, Portland OR (2003)

Status Report on Multi-Cell Superconducting Cavity Development for Medium-Velocity Beams, W. Hartung, et al.

Experimental Study of a 322 MHz v/c=0.28 Niobium Spoke, T.L. Grimm, et al.

Cryomodule Design for the Rare Isotope Accelerator, T.L. Grimm, et al.

X-ray Tomography of Superconducting RF Cavities, S. Musser, et al.

Mechanical Properties of Electron Beam Welds in High Purity Niobium, T. Bieler, et al.

The Beam Dynamics Studies of Combined Misalignment and RF Errors for RIA, X. Wu, et al.

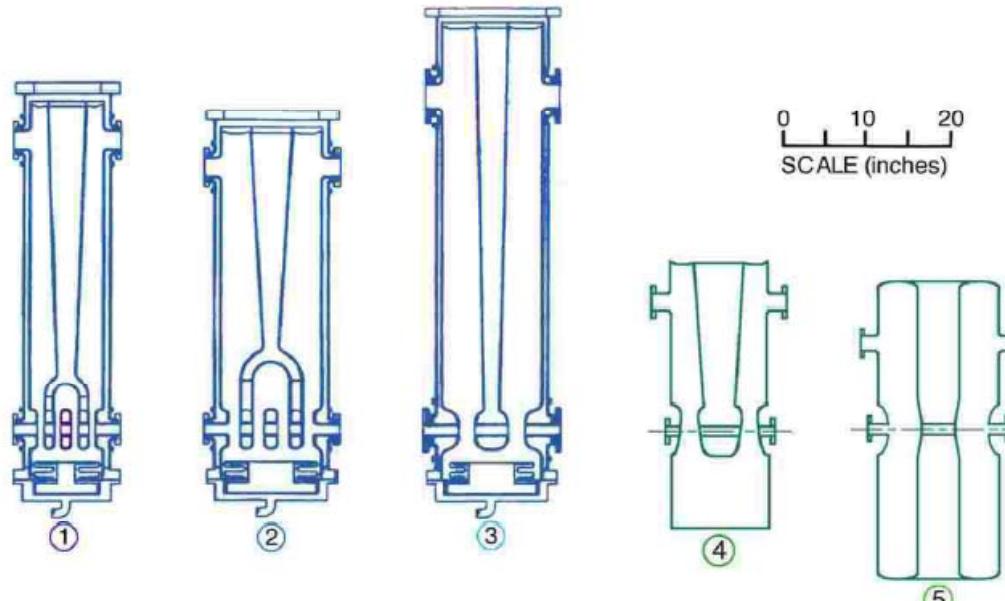
Instabilities Study and Applications for the RIA Project, D. Gorelov, et al.

Overview of Radioactive Ion Accelerators, B. Sherrill.

SC-DTL Comparison

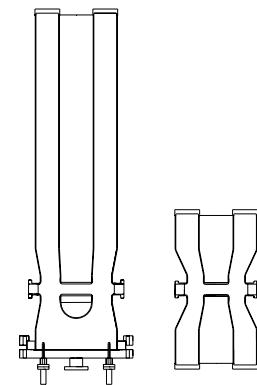
MICHIGAN STATE
 UNIVERSITY UNIVERSITY

ANL
14th harmonic
57.5MHz



MSU
10th harmonic
80.5MHz

**80.5MHz QWR
 (Legnaro)**
 Prototyped
 Cryomodule



322MHz HWR
 Prototyped

Double-Spoke
 Prototyped